Innovative roofing system for reducing solar heat gain from natural light under Malaysian sky conditions

By

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This research presents a study on the design of a new model of roofing system for improving indoor climatic conditions in single storey buildings of the Malaysian environment.

There are general issues leading to pursue this research:

• The increasing demand for cooling energy in Malaysian buildings is serious.

• Roofing system represents the main source of heat build-up in single storey buildings and low cost houses which contributes about 70% of the total heat gain.

• Single storey buildings in tropics rarely have roof lights simply because of GHG effect and in thermally uncomfortable at human height level.

• Existing and new buildings in the tropical Malaysia would have a major problem when energy price increase over time.
Main problems

- Skylight roofing system cannot simply be applied in tropical region and particularly in single storey buildings due to the concentration of tropical sun with unpredictable and weak wind movement in urban areas which increases heat gain and brings in thermal discomfort at human height level.

- In Malaysia, skylights heat up the interior quickly, in previous years and currently, air conditioning helps to cool the air mass to overcome thermal discomfort but with the gradual increase in energy cost this system is no more considered as a tropical design element.

- Stifling heat and glare would be a major problem and thus the raw exposure of this amount needs to be tampered for productive use of the sunlight energy.
Research Main Objective

The main goal of this study is to design a special roofing system under Malaysian climatic condition for single storey building (low cost), which allows for natural light while overcoming the heat accumulation problem to provide cooler natural light.
The novelty of research

- The review of literature found no specific standard to encourage the use of this type of approach in roofing systems, and no specific policy measure related to this technique is found in the building codes, such as Uniform Building By-Laws, Malaysian Standard MS1525-2007, Green Building Index, and Building Sector Energy Efficiency Project.

- Ong (2011), Ismail et al. (2011), Al Yacouby et al. (2011), Sheng (2011), Ismail et al. (2012), and Yew et al. (2013) introduced a number of approaches to develop the roofing system in Malaysia. However, none of these studies combined daylighting and passive cooling techniques in one roofing design. The proposed design is a novel approach because no roofing system globally combines this technique.
Researches


• There are just several examples of sustainable roofs such as Green Roof Systems (Garden Roof System), Reflective Roofs (Cool Roof) and Roof Photovoltaic. However, this research presented a new model of sustainable roofing design for single storey buildings in the tropics.

<table>
<thead>
<tr>
<th>Green roofs</th>
<th>Reflective roofs</th>
<th>Roof Photovoltaic</th>
</tr>
</thead>
</table>

• As a result, it is found that exploring a new approach as the IRS will be an original and new application locally and globally.
Research design

Figure 1: OII process classifying independent and dependent variables
As the aim of the study requires delivering cooler natural light, the research targeted the most significant techniques which relate to the physical characteristics of light and heat (low cost).

Figure 2: Classification of passive cooling methods in energy efficient buildings (Geetha and Velraj, 2012) with highlighting of the targeted variables
(Red dashed lines are the targeted approaches in this research)
Roofing design in the tropics needs to adopt a combination of several approaches as passive and active solar methods because Malaysian condition cannot rely only on passive practices.
Research Gap

The review also indicated that there are some areas which have not been covered in the past:

• The effectiveness of integrated two rooflight systems in the roof and in the attic with different configurations and sizes.

• The effectiveness of the polycarbonate materials as a multi layers with specific parameters especially in Malaysian single storey buildings with height of 3 meters which remain uncertain.

• The effectiveness of reflective and radiative roof design as one strategy in roofing system.

• The effectiveness of hybrid turbine ventilator in specific volume size with particular architectural roofing design.

• The effectiveness of combining these strategies in one roofing design to extract heat from natural light in the attic space before it reaches the occupant zone.
Roofing Design and Experimental Methods

Physical Experimental Methods

These methods were adopted because from the architectural point of view, the simulation and the full-scale physical experimental method represent the optimum approach in providing most reliable data of the solar performance in the actual building size.

As a result, a set of physical experimental investigations has been conducted which was divided into two main sections

1- Simulation study
2- and full-scale field studies (Empirical Research).
The study highlighted the outcomes of the roofing system through several components in typical room size. This is to identify the reliability and the effectiveness of the roofing system to enhance the performance of the IRS.

<table>
<thead>
<tr>
<th>Strategies</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage (1)</td>
<td></td>
</tr>
<tr>
<td>Roof Materials</td>
<td>Concrete</td>
</tr>
<tr>
<td>Roof Colours</td>
<td>Black</td>
</tr>
<tr>
<td>Roof Angles</td>
<td>30°</td>
</tr>
<tr>
<td>Glazing Materials</td>
<td>Single and Double Clear Glass</td>
</tr>
<tr>
<td>Rooflight Size</td>
<td>1m x 0.5m</td>
</tr>
<tr>
<td>Building Orientations</td>
<td>30°</td>
</tr>
<tr>
<td>Stage (2)</td>
<td></td>
</tr>
<tr>
<td>Roof with Attic</td>
<td>without ceiling</td>
</tr>
<tr>
<td>Ceiling Light Size</td>
<td>4m x 2m</td>
</tr>
<tr>
<td>Black Body Concept</td>
<td>without Black</td>
</tr>
<tr>
<td>Attic Ventilation</td>
<td>without ventilation</td>
</tr>
</tbody>
</table>

Figure 4: The proposed model of the IRS based on the simulation results
Simulation Study

• Before conducting the full scale empirical measurement, the simulation data requires to be verified to ensure the reliability of overall methodology. A building energy simulation tool used for the investigations is “Integrated Environmental Solutions” (IES).

• Investigate the potential and the reliability of several roofing components and strategies to improve indoor climatic conditions under the Malaysian climate condition.

• Determine the appropriate model of the IRS to extract heat in comparison to different roofing systems.
Daylight condition
(Allowed for natural light inside the model)

Dark condition
(during daytime without permitting any source of light)

Total darkness

Natural light
Visible light transmittance (VT) = 0.76
Solar Heat Gain Coefficient (SHGC) (centre-pane) = 0.1891

\[
\text{LSG} = \frac{\text{visible light transmittance (VT)}}{\text{solar heat gain coefficient (SHGC)}}
\]  

(4.1)

According to this result and the results of the simulation studies, it is proved that double polycarbonate glass material is very effective and efficient to be applied and used for the empirical studies.
Experimental Model Description

• The test cell is a single-storey model located at the school of Housing, Building and Planning in the main campus site of Universiti Sains Malaysia (USM), Penang (latitude 5° 2’N and longitude 100° 2’E),

• This test building was built with conventional construction materials. The floor slab was made with concrete, the walls with plaster brick, the ceiling with plaster board and the pitched roof with corrugated metal. Double polycarbonate was used for glazing in the roofing system.

Figure 8: Test cell location
Field Study

Studying the performance of Innovative Roofing System (IRS)

Roof without Attic  IRS  Roof with Attic

Dark and Daylight Conditions

Effectiveness in improving indoor climatic condition and separate solar light from solar heat

Figure 9: Summary of different strategies of field studies to investigate the performance of the Innovative Roofing System (IRS) in the real building

Figure 10: Model design for the purpose of Roof without Attic

Figure 11: Model design for the purpose of Roof with Attic
Innovative Roofing System

(a) Inlet at gable end and the location of HTV

(b) View of ceiling and daylighting system from inside the room

(c) View of HTV from inside the attic

(d) Solar panel and Turbine Ventilator

(e) Turbine fan

Figure 12: IRS
4.4.2.1 Measurement Set-Up and Instrumentations

L= Illuminance, 1 = Temperature (DBT), 2 = MRT, 3 = Relative humidity, 4 = Air velocity, 5 = surface temperature, 6 = Solar panel and HTV and 7 = DAQ system and 8 = Outdoor station (air temperature, relative humidity, solar radiation, illuminance and wind speed).

Figure 13: Measurement equipment for data collection
Data collection and analysis

• Data from all sensors were recorded in the data acquisition system continuously at 10-min intervals from 07:30 am to 07:00 pm for three clear days per strategy and condition and presented half hourly.

• This study conducted a comparison of several profiles of air temperatures, globe temperature (mean radiant temperature), illuminance level, and air velocity for the three-clear-day period of each strategy and condition. This three-day period was selected based on several studies conducted for the same environment (hot-humid), such as field studies by Ismail (2010), Ismail and Abdul Rahman (2010), Ong (2011), Al Yacouby et al. (2011) and Rahman (2012).

• Comparing the performance of the different roofing systems during the various days indicated that each day had slightly different climatic conditions. Therefore, a simplified comparison using the relativeness index (RI) as an indicator was conducted to formulate general and subjective conclusions, Khedari et al. (2000; 2002), Ismail (2010), Ismail and Abdul Rahman (2010).
Main Results
6.4.1.1 Indoor Air Temperature

Figure 14: Comparison of difference between indoor - outdoor temperature for different roofing strategies in two conditions dark and daylight

Table 1: Statistical values of outdoor and indoor air temperature for different roofing system strategies for 3 days measurements period

<table>
<thead>
<tr>
<th>Opening</th>
<th>Outdoor air temperature (°C)</th>
<th>Indoor air temperature (°C)</th>
<th>Indoor-outdoor difference (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Max</td>
<td>Mean</td>
<td>Mean Min</td>
</tr>
<tr>
<td><strong>Dark</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof (no) attic</td>
<td>35.16</td>
<td>32.55</td>
<td>26.26</td>
</tr>
<tr>
<td>Roof (with) attic</td>
<td>35.59</td>
<td>32.85</td>
<td>26.49</td>
</tr>
<tr>
<td>IRS</td>
<td>35.34</td>
<td>33.36</td>
<td>28.67</td>
</tr>
<tr>
<td><strong>Daylight</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roof (no) attic</td>
<td>35.30</td>
<td>32.48</td>
<td>26.29</td>
</tr>
<tr>
<td>Roof with attic</td>
<td>35.97</td>
<td>33.28</td>
<td>27.84</td>
</tr>
<tr>
<td>IRS</td>
<td>35.59</td>
<td>32.93</td>
<td>27.23</td>
</tr>
</tbody>
</table>
6.4.1.2 Mean Radiant Temperature

Figure 15: Comparison of difference between mean radiant temperature – indoor air temperature for different roofing strategies in two conditions dark and daylight

Table 2: Statistical values of mean radiant temperature for different roofing system strategies for 3 days measurements period
6.4.1.3 Attic Air Temperature

Figure 16: Comparison of difference between attic temperature – outdoor air temperature for 2nd and 3rd roofing strategies in two conditions dark and daylight

Table 3: Statistical values of outdoor and attic air temperature for different roofing system strategies for 3 days measurements period

<table>
<thead>
<tr>
<th></th>
<th>Outdoor air temperature (°C)</th>
<th>Attic air temperature (°C)</th>
<th>Attic – outdoor difference (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Max</td>
<td>Mean</td>
<td>Mean Min</td>
</tr>
<tr>
<td>Dark</td>
<td>35.59</td>
<td>32.85</td>
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<tr>
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<tr>
<td>Daylight</td>
<td>35.59</td>
<td>32.93</td>
<td>27.23</td>
</tr>
</tbody>
</table>
6.4.3 Illuminance (Daylight Level)

Figure 17: Half-hour variations in illuminance recorded by five sensors (average) for the three different types of roofing systems during 12 h (daytime)

Table 4: Percentage of daylight levels recorded by five sensors (8:30 am to 6:00 pm) per average of half an hour for the three different roofing strategies
6.4.4 Air Velocity

Figure 18: Correlation between solar radiation intensities and indoor air velocity (mean) in the attic zone when IRS is used; (a) dark condition (b) daylight condition

Table 5: Statistical values of solar radiation and attic air velocity for IRS for 3 days measurements period

<table>
<thead>
<tr>
<th>Solar radiation (W/m²)</th>
<th>Inlet air velocity (m/s)</th>
<th>Outlet air velocity (m/s)</th>
<th>Mean air velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>Max</td>
<td>Mean</td>
<td>Min</td>
</tr>
<tr>
<td>952</td>
<td>541</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Daylight</td>
<td>1061</td>
<td>583</td>
<td>66</td>
</tr>
</tbody>
</table>
Conclusions

• The combination of different passive design strategies contributed in improving the indoor environment, especially during daylight condition.

• The results revealed that IRS improved under daylight condition by 121% compared with the first strategy and by 22% compared with the second strategy.

• For the attic space, IRS was compared with the second strategy only (roof with an attic). The findings on attic temperature showed that IRS was able to reduce the temperature by 5.4 °C under the daylight condition.
The maximum outdoor illumination exceeded 110,000 lux and affected the indoor environment considerably. The percentage of daylight level from 8:30 am to 6:00 pm in the room zone showed that

- The first strategy (roof without an attic), approximately 45% to 65% of illuminance was below 700 lux.

- The second strategy (roof with an attic), approximately 50% to 70% of illuminance was below 700 lux.

- The third strategy (IRS) showed readings almost similar to those in the second strategy because both of them have the same daylight system. The readings showed that around 55% to 75% of illuminance was below 700 lux.

This investigation revealed the capability of double polycarbonate to diffuse and bring in more natural light whilst reducing the level of solar heat in the worst case condition.
**IRS Performance**

- Maximum outdoor air temperature about 35°C
- Maximum outdoor illuminance about 115,000 lux
- Maximum solar radiation about 1000 W/m²

(Daylight – Dark)

- Indoor air temperature: 1st strategy was 0.8°C while the IRS was less with 0.31°C
- MRT 1st strategy was 3.14°C while the IRS was less with 2.22°C
- Attic air temperature was 0.38°C
- The maximum speed of outlet around 2.17 m/s for dark condition while 2.45 m/s for daylight
Thank you